1975
USDA Forest Service Research Paper PNW-195

Comparison of Western Spruce Budworm Populations and Damage on Grand Fir and Douglas-fir Trees

V.M. Carolin
W.K. Coulter

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. Department of Agriculture Forest Service Portland, Oregon

COMPARISON OF WESTERN SPRUCE BUDWORM POPULATIONS AND DAMAGE ON GRAND FIR AND DOUGLAS-FIR TREES

Reference Abstract

Carolin, V. M., and W. K. Coulter
1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

RESEARCH SUMMARY
Research Paper PNW-195
1975

The increasing abundance of grand fir in stands of the mixed conifer type in eastern Oregon and Washington could intensify the hazard posed by the western spruce budworm. A preliminary study indicated that grand fir suffered serious damage and Douglas-fir minor damage after a 4-year period of visible infestation. Subsequent studies were based on paired-tree observations to clarify damage relationships between the western spruce budworm and grand fir, for comparison with Douglas-fir.

Damage was consistently higher on grand fir than on Douglas-fir in each study but was not the result of higher budworm populations. Egg populations on the two species were similar in the upper crown third, but Douglas-fir had significantly higher populations than grand fir in the lower crown third. Density of larvae per unit of new shoots was similar between the two tree species; number of larvae per twig lot usually differed.

With more intensive larval sampling, early damage on grand fir can probably be predicted with some confidence. These studies indicated that 10-tree cluster plots were a minimum basis for sampling to obtain sufficient data for regression analysis. Although percent defoliation of new growth is an index to the incidence of damage, particular attention should be paid to bud-killing and top-killing on grand fir.

CONTENTS

INTRODUCTION

The western spruce budworm (*Choristoneura occidentalis* Freeman) is the most widely distributed and destructive forest defoliator in western North America (Carolin and Honing 1972). Its larvae mine needles, bore into vegetative buds and staminate flowers, then feed on the expanding new growth. They will feed on old foliage if the new growth is destroyed by feeding or frost. Effects on trees include needle loss, loss in radial and height increment, top-killing, and tree mortality. In the northern Rocky Mountains, larvae often destroy green cones.

In eastern Oregon and Washington, the budworm is especially damaging to grand fir (*Abies grandis* (Dougl.) Lindl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Forest practices have changed tree species composition in the east-side mixed conifer forests, and Edgerton (1973) considers these forests now to be dominated by grand fir. Increasing abundance of grand fir may lead to an intensification of the budworm problem. In studies at the end of a 12-year outbreak in northeast Oregon, Williams (1966, 1967) found that external damage symptoms indicated degrees of reduction in radial increment and that grand fir suffered heavier damage than Douglas-fir.

Budworm populations increase gradually, rather than explosively. Thus the intensity of early feeding damage should provide a basis for predicting economic growth losses more than a year before they occur. However, these predictions should be based on reactions of different tree species and their abundance.

Prediction is usually based on insect population levels and a convenient correlated indicator of damage. Some predictive capacity has been developed for the western budworm on Douglas-fir, and population levels are used to predict the degree of defoliation of new growth. To predict defoliation, a sequential plan has been developed for egg mass surveys in the central and southern Rocky Mountains (McKnight et al. 1970); and tables relating egg mass density and density of small larvae to categories of defoliation have been prepared for eastern Oregon (Carolin and Coulter 1972). In the absence of separate guidelines for grand fir and other associated species, there has been a tendency to apply the standards for Douglas-fir to these species.

During our budworm studies on Douglas-fir, as opportunity occurred, we attempted to compare populations and damage between grand fir and Douglas-fir by means of paired observations on the two species. At this time (1955-62), extensive control programs were in full swing and our choice of study areas was limited. When grand fir and Douglas-fir were intermixed, one usually predominated. More often the two species occurred in separate but adjacent stands. The number of comparisons was limited, but perhaps sufficient to identify differences in budworm damage and populations between the two species.

For purposes of evaluation surveys, the following questions are posed as a basis for interpreting data obtained.

1. Do adjacent grand fir and Douglas-fir trees show differences in damage early in the development of an outbreak?
2. Are differences in damage between the two tree species explained by differences in budworm density and distribution?
3. Can defoliation of new shoot growth on grand fir be reliably predicted from samples of feeding larvae?

METHODS

A brief summary of individual studies, by objective, is shown below. Its purpose is to clarify the chronology of the different studies and the occasional conduct of different studies in the same locality in the same time period.

Studies	Years	Locality
Early tree damage (defoliation, top-killing, bud-killing)	1955	North Powder, Oreg.
	1956-59	Baker, Oreg.
	1958-59	Halfway, Oreg.
Budworm density and distribution:		
Egg masses	1958-59	Halfway, Oreg.
	1960-61	Goldendale, Wash.
Larvae	1956-57	Baker, Oreg.
	1959	Halfway, Oreg.
	1962	Goldendale, Wash.
Correlation of larval density and defoliation	1959	Halfway, Oreg.
	1960-61	Goldendale, Wash.

EARLY TREE DAMAGE

Damage criteria included percent defoliation of current needle growth, percent defoliation of all needle growth, presence or absence of top-killing, and incidence of bud-killing. Defoliation estimates were made for each crown third by observers using fieldglasses. A single estimate for the tree was obtained by weighting crown third estimates as follows: upper--1, middle--3, and lower--5 (Carolin and Coulter 1972). Killed tops were identified by dead wood, color of the leader, absence of buds and needles, and development of lateral shoots into multiple leaders. Bud-killing was arbitrarily classified as low, moderate, or high. The "low" category was applied when 15 percent or less of the buds were killed; "high" was defined as more than 50 percent.

A preliminary study compared both current and cumulative tree damage on grand fir and Douglas-fir after 4 years of generally visible feeding at a plot near North Powder, Oregon. At the beginning of an infestation, a plot was established,

consisting of 10 subplots 5 chains apart on a compass line; each subplot was a cluster of three trees. During 1951 through 1954, egg and larval populations were sampled and broad estimates of current defoliation made each year. Final damage estimates were obtained in early spring of 1955. Although estimates were made at nine subplots, direct comparisons between codominants and intermediates of the two species were possible at only three subplots. At these subplots, grand fir was twice as abundant as Douglas-fir. An adjacent subplot had been logged, and in six other subplots Douglas-fir greatly predominated. In the summer of 1955, the plot and general area were sprayed with DDT in an extensive budworm control project.

Starting in 1956, a second study on cumulative damage was based on five pairs of lightly defoliated intermediate grand fir and Douglas-fir trees near Baker, Oregon, in a gulch next to a long-term Douglas-fir plot. Pairs were located on a line, with each pair 1 chain apart. In 1956 and 1957, trees were sampled for density of full-grown larvae; but no fieldglass estimates of defoliation were made. In 1958, plot trees accidentally received a light coverage of DDT spray. Estimates of top-kill and bud-kill were made in both 1958 and 1959. Comparisons between the two species were on an empirical basis.

In a third study, damage was compared on 10 numbered pairs of codominant trees in 1958 and 1959 at a cluster plot near Halfway, Oregon. Light defoliation was first observed during a ground reconnaissance in 1956. In 1958, defoliation estimates were made on 5 pairs by one observer and in 1959 on all 10 pairs by two observers. Condition of tops was examined in both years. In 1958, incidence of bud-killing was classified in a general way; and in 1959, sample twigs were examined and percent buds killed was recorded for each tree. Analysis of variance was used to test for significant differences in defoliation and bud-kill between species.

BUDWORM DENSITY AND DISTRIBUTION

Egg masses.--Densities of egg masses on five pairs of trees were compared at the previously mentioned cluster plot near Halfway, Oregon, in 1958 and 1959. This was a light infestation; hence comparisons were made only at midcrown. Two whole branches from each of five trees of each species were cut and examined and new egg masses expressed both on a branch basis and per thousand square inches of foliated branch area. Differences in density, using the two units, were tested for tree species and years by analysis of variance and the t-test. This study was terminated at the end of 1959 because of a general decline in infestations in northeast Oregon.

The next comparisons were made in 1960 and 1961 in a rapidly arising infestation near Goldendale, in the eastern Washington Cascades. In both years, density of egg masses by crown height on grand fir alone was estimated by sampling low, middle, and upper crown thirds on the same 5 trees in a 10-tree cluster plot. In the second year, at a second plot, similar observations were made on five pairs of grand fir and Douglas-fir. Sampling involved removing and counting

new egg masses on two whole branches in the upper third, two longitudinal half-branches in the middle third, and one whole branch in the lower third. The single branch from the lower third contained about the same amount of foliage area as the two middle third branches. Number of egg masses was expressed both on a branch basis and per thousand square inches of foliage. For grand fir alone, analysis of variance was to determine significant differences in egg mass density between crown levels. For the grand fir-Douglas-fir comparisons, analysis of variance was to determine significant differences between crown levels and between tree species. Separate analyses were run for the two expressions of egg mass density.

Larvae.--Densities of full-grown larvae were compared in both 1956 and 1957 on the five pairs of grand fir and Douglas-fir used in the damage study at the Baker plot. Each tree was sampled by cutting four 15-inch twigs at random from the lower crown half, using a pole-pruner. Both spruce budworm and new shoots on each twig sampled were counted. Larval density was expressed as number of larvae per four 15-inch twigs and per 100 buds or new shoots on these twigs. Differences in density between tree species were tested by analysis of variance.

Densities of budworm larvae in opening shoots were compared on paired codominants of the two species at the Halfway plot in 1959 and at the Goldendale plot in 1962. In the 1959 and 1962 studies, 10 and 5 pairs of trees, respectively, were used. Populations were low to medium at Halfway and high at Goldendale. Sampling techniques were as described for the Baker study. However, at Halfway six twigs and at Goldendale four twigs were a twig lot.

CORRELATION BETWEEN LARVAL DENSITY AND DEFOLIATION

This effort was aimed principally at grand fir, because the relationship between larval density and percent defoliation of current growth had been established for Douglas-fir in eastern Oregon. However, comparisons of the larvae-damage relationship were attempted between species at the same or adjacent plots where possible.

At the Halfway plot in 1959, 10 trees of each species were sampled for bud-feeding larvae and defoliation estimates (already noted) made in fall. Regression analyses were run between percent defoliation of current growth and number of larvae, and also larvae per 100 shoots. Similar efforts were made in 10-tree cluster plots in the Goldendale area, but these were single-species plots. They consisted of: one grand fir plot sampled in both 1960 and 1961; one Douglas-fir plot, less than one-half mile away, in both 1960 and 1961; and a second grand fir plot sampled only in 1961. Four 15-inch twigs constituted the larval sample, and number of new shoots was counted on each twig. Whereas populations at Halfway drastically declined the following year, those at Goldendale were in a rapidly increasing infestation which was sprayed in 1962.

RESULTS

EARLY TREE DAMAGE

In the preliminary study at the North Powder plot, grand fir trees showed more damage than adjacent Douglas-fir trees in the same crown class (table 1). Grand fir had higher defoliation of 1954 needle growth and all needle growth than Douglas-fir, except for intermediates at plots 2 and 8 where defoliation was similar. Grand fir had a high incidence of bud-killing; with one exception, Douglas-fir had low bud-kill. Of 6 codominant grand fir, 3 had dead tops; 10 of 12 intermediate grand firs were top-killed. Douglas-fir trees all had living tops. In previous studies, generalized estimates of current defoliation were as follows: 1951--light; 1952--light; 1953--light to moderate; and 1954--heavy. Thus, after 2 years of generally visible light defoliation followed by 2 years of higher defoliation, grand fir showed serious crown damage and Douglas-fir minor crown damage.

In the paired five-tree study at the Baker plot, total defoliation was not estimated; but other criteria showed that grand fir trees were damaged more than Douglas-fir. In 1958, three grand firs had tops defoliated but alive, one had its top killed with two new leaders developing, and one had a killed top with no recovery evident. In 1959, a year after the DDT spraying, four of the grand fir trees showed leader growth; the fifth showed no recovery. Bud-kill on the fifth tree, particularly in the middle and upper crown thirds, was high. In contrast, all five Douglas-fir trees had living leaders and virtually no bud-kill. In addition to harboring a budworm infestation, the Douglas-fir trees had an infection of a needle-blight fungus (*Rhabdocline* sp.) which caused conspicuous defoliation in 1959.

At the Halfway plot, average defoliation of current growth was twice as high on grand fir as on Douglas-fir (table 2). The differences were significant[1/] in 1958 and highly significant in 1959. Bud-kill in 1958 was inconsequential on both species; in 1959, it averaged higher on grand fir than on Douglas-fir (table 2); but the difference was not significant. No top-killing occurred in this light infestation. Tops of both species had light defoliation (less than 25 percent) in 1958; grand fir tops were heavily defoliated in 1959.

BUDWORM DENSITY AND DISTRIBUTION

Egg masses.--In the light infestation at Halfway, egg mass density at mid-crown was higher on Douglas-fir than on grand fir (table 3); but in neither year was the difference significant. Relative variation was typically high for these low populations, and adjustment of egg mass counts to a common foliated branch area basis tended to raise egg mass densities on grand fir because of its smaller branch size. At any rate, there is no evidence that the higher defoliation on grand fir recorded for 2 years at this plot was due to higher egg mass density on this species.

1/ *In this paper, $p < 0.05$ is significant, and $p < 0.01$ is highly significant.*

Table 1.--*Damage on grouped Douglas-fir and grand fir trees after 4 years of visible feeding, North Powder, Oregon, spring of 1955*

Subplot and tree species	Dominants and codominants					Intermediates				
	Number of trees	Defoliation		Other damage		Number of trees	Defoliation		Other damage	
		1954 growth	All growth	Bud-kill1/	Top-kill		1954 growth	All growth	Bud-kill1/	Top-kill
		-Average percent-		--Incidence--			-Average percent-		--Incidence--	
1:										
Douglas-fir	3	31	5	Low	None	5	18	5	Low	None
Grand fir	0	--	--	--	--	0	--	--	--	--
2:										
Douglas-fir	3	26	5	Low	None	5	23	5	Low	None
Grand fir	0	--	--	--	--	2	16	5	Low	None
3:										
Douglas-fir	3	33	5	Low	None	5	10	5	Low	None
Grand fir	0	--	--	--	--	0	--	--	--	--
4:										
Douglas-fir	2	16	5	Low	None	5	12	5	Low	None
Grand fir	0	--	--	--	--	0	--	--	--	--
5:										
Douglas-fir	3	22	10	Low	None	5	13	5	Low	None
Grand fir	0	--	--	--	--	0	--	--	--	--
6:										
Douglas-fir	2	61	13	Low	None	0	--	--	--	--
Grand fir	3	94	21	Low to high	None	5	87	24	High	All
7: Trees logged	--	--	--	--	--	--	--	--	--	--
8:										
Douglas-fir	0	--	--	--	--	2	98	39	Low to high	None
Grand fir	3	97	29	2/High	All	5	99	33	High2/	All
9:										
Douglas-fir	0	--	--	--	--	4	60	8	Low	None
Grand fir	0	--	--	--	--	0	--	--	--	--
10:										
Douglas-fir	2	57	6	Low	None	5	23	5	Low	None
Grand fir	0	--	--	--	--	0	--	--	--	--

1/ Low indicates 15 percent or less, and high 50 percent or more, of the buds killed.
2/ Nearly complete bud-kill on these trees.

Table 2.--*Damage on paired Douglas-fir and grand fir trees during 2 early years of visible feeding, Halfway, Oregon, 1958-59*

Year and tree number	Current defoliation		Bud-kill	
	Douglas-fir	Grand fir	Douglas-fir	Grand fir
	- - - - - - - -	Percent	- - - - - - - -	
1958:				
2	10	44	<10	<10
4	16	69	<10	<10
6	9	42	<10	<10
8	23	24	<10	<10
10	23	35	<10	<10
Average	16.2	42.8		
1959:				
1	29	62	9	21
2	8	57	5	36
3	20	37	12	16
4	17	43	11	9
5	20	31	13	19
6	9	62	14	17
7	15	43	10	32
8	34	40	19	12
9	18	25	5	10
10	27	27	5	8
Average	19.7	42.7	10.3	18.0

Table 3.--*Egg mass densities on two branches at midcrown on paired Douglas-fir and grand fir trees in a light infestation near Halfway, Oregon, 1958-59*

Year and tree number	Douglas-fir		Grand fir	
	Foliage area	Egg masses	Foliage area	Egg masses
	M in^2	Number	M in^2	Number
1958:				
2	4.472	5	3.180	1
4	3.780	2	3.376	10
6	3.985	2	2.344	2
8	4.783	2	2.268	0
10	3.700	19	1.241	2
Total	20.720	30	12.409	15
Column mean	--	6.0	--	3.0
Adjusted mean[1/]	--	5.93	--	3.07
1959:				
2	4.634	8	1.180	0
4	2.526	1	3.507	1
6	2.990	3	2.516	1
8	3.026	4	1.248	2
10	2.733	6	1.667	0
Total	15.909	22	10.118	4
Column mean	--	4.4	--	0.8
Adjusted mean[1/]	--	3.75	--	1.45

[1/] Adjusted to average foliated branch area for all tree samples.

In the heavy infestation in 1961 at Goldendale, where interspecies comparisons were made at three crown heights, significantly higher numbers of egg masses per branch were found in the lower and middle crown thirds of Douglas-fir trees, as compared with grand fir. Egg masses per thousand square inches are significantly higher in the lower third of Douglas-fir, but differences were not significant between the two species at the middle and upper thirds. Without the covariance correction for branch size, egg mass density in the middle third, as well as the lower third, becomes significantly higher on Douglas-fir. Simplified, the results show similar egg mass densities in the upper crown of the two tree species and dissimilar densities in the lower crown; egg masses were more uniformly distributed on the Douglas-fir trees (table 4).

Table 4.--*Vertical distribution of egg masses on sample branches from paired Douglas-fir and grand fir trees near Goldendale, Washington, 1961*

Tree number	Douglas-fir						Grand fir					
	Lower third of crown		Middle third of crown		Upper third of crown		Lower third of crown		Middle third of crown		Upper third of crown	
	Foliage area	Egg masses	Foliage area	Egg masses	Foliage area	Egg masses	Foliage area	Egg masses	Foliage area	Egg masses	Foliage area	Egg masses
	M in^2	Number	M in^2	Number	M in^2	Number	M in^2	Number	M in^2	Number	M in^2	Number
1	2.614	39	1.625	34	1.710	107	2.660	2	2.040	43	1.556	74
2	4.510	114	4.026	196	3.443	180	1.938	2	2.331	32	1.127	31
3	4.301	129	4.169	106	1.606	60	5.040	46	2.278	59	1.822	67
4	3.120	110	2.822	167	1.903	123	2.728	39	3.107	73	1.834	105
5	2.747	41	2.137	101	2.506	82	3.397	16	2.400	43	1.611	62
Total	17.292	433	14.779	604	11.168	552	15.763	105	12.156	250	7.950	339
Column mean	--	86.60	--	120.80	--	110.40	--	21.00	--	50.00	--	67.80
Adjusted mean [1/]	--	83.07	--	111.31	--	94.42	--	24.53	--	59.49	--	83.78

[1/] Adjusted to average foliated branch area for all tree samples.

The 2-year study in a grand fir plot at Goldendale confirmed the egg mass distribution pattern for grand fir found in the paired species test. In both years, number of egg masses per branch was lowest in the lower crown third and generally similar in the middle and upper thirds (table 5). Numbers of egg masses in the lower third were significantly different in 1960 but not in 1961. Egg masses per thousand square inches of foliage were very low in the lower third but increased progressively up the tree. In both years, densities in the lower third were significantly less than in the middle and upper crown thirds. Thus there is substantial evidence that the egg deposition pattern on grand fir differs from that on Douglas-fir reported by Carolin and Coulter (1972).

Table 5.--*Vertical distribution of egg masses on sample branches from grand fir trees near Goldendale, Washington, 1960-61*

Year and tree number	Lower third of crown		Middle third of crown		Upper third of crown	
	Foliage area	Egg masses	Foliage area	Egg masses	Foliage area	Egg masses
	M in^2	Number	M in^2	Number	M in^2	Number
1960:						
1	5.525	3	7.474[1/]	15[1/]	3.721	13
2	3.150	1	2.223	4	1.707	10
5	1.888	0	2.048	5	1.926	7
6	2.492	4	1.364	5	1.011	10
8	2.822	1	1.717	7	1.285	10
Total	15.877	9	14.826	36	9.650	50
Column mean	--	1.80	--	7.20	--	10.00
Adjusted mean[2/]	--	1.13	--	6.82	--	11.05
1961:						
1	2.268	5	2.286	6	3.993	57
2	3.867	0	2.587	15	5.712	26
5	4.128	2	1.927	7	1.760	18
6	2.016	11	1.252	46	1.026	36
8	2.600	6	3.146	47	1.362	28
Total	14.879	24	11.198	121	13.853	165
Column mean	--	4.80	--	24.20	--	33.00
Adjusted mean[2/]	--	4.63	--	24.43	--	32.94

[1/] Two whole branches, rather than two half-branches, were examined.

[2/] Adjusted to average foliated branch area for all tree samples.

Larvae.--Comparisons in 1956 and 1957 at the Baker plot showed that average number of larvae per twig lot could differ considerably between species but that number per 100 shoots would be similar (table 6). In 1956, there was no significant difference between species in number either per twig lot or per 100 shoots. Average number of shoots per twig was generally similar: 43.6 on grand fir and 38.1 on Douglas-fir. In 1957 there was a significant difference in number of larvae per twig lot, with 31.4 for grand fir and 13.2 for Douglas-fir, but no significant difference in larvae per 100 shoots, with 13.3 for grand fir and 12.9 for Douglas-fir. Differences in numbers of shoots per twig between species, about 59 for grand fir and 28 for Douglas-fir, appeared to be a compensating factor in the 1957 sampling. However, because these comparisons were of full-grown larvae, the possibility of an artifact based on redistribution of the growing larvae was recognized. Subsequent studies were thus directed to larvae in opening buds.

Table 6.--*Numbers and density of full-grown larvae on paired Douglas-fir and grand fir trees, Baker, Oregon, 1956-57*

Year and tree number	Douglas-fir		Grand fir	
	On 4 twigs	Per 100 shoots	On 4 twigs	Per 100 shoots
	- - - - - - - - Number of spruce budworm - - - - - - - - - -			
1956:				
1	25	19.5	21	20.2
2	31	18.0	27	11.3
3	10	17.9	9	7.8
4	20	10.6	8	6.3
5	22	10.1	38	13.2
Average	21.6	15.22	20.6	11.76
1957:				
1	13	17.1	32	16.9
2	29	25.0	35	14.2
3	8	10.7	47	17.9
4	8	7.8	17	8.7
5	8	4.1	26	8.8
Average	13.2	12.94	31.4	13.30

At the Halfway plot, number of bud-feeding larvae per twig lot (six 15-inch twigs) was significantly higher on grand fir than on Douglas-fir, with means of 50.1 and 18.9, respectively. However, number per 100 shoots was not significantly different, with means of 18.5 for grand fir and 15.2 for Douglas-fir (table 7). There were more new shoots per 15-inch twig on grand fir (mean of 45.7) than on Douglas-fir (mean of 19.5).

Table 7.--*Numbers and density of larvae in opening buds on paired Douglas-fir and grand fir trees, Halfway, Oregon, 1959*

Tree number	Douglas-fir		Grand fir	
	On 6 twigs	Per 100 shoots	On 6 twigs	Per 100 shoots
	Number of larvae			
1	39	22.9	36	20.4
2	26	29.2	70	25.3
3	5	4.5	54	14.8
4	8	5.6	76	19.4
5	15	16.0	42	16.6
6	1	1.9	38	12.8
7	11	12.4	35	18.9
8	63	47.0	41	17.3
9	4	5.3	75	27.7
10	17	7.4	34	11.6
Average	18.9	15.22	50.1	18.48

At the 1962 Goldendale plot, number of bud-feeding larvae per twig lot (four 15-inch twigs) was much higher on grand fir, with a mean of 127.2, than on Douglas-fir, with a mean of 69.8, but the difference was not statistically significant. Number of larvae per 100 shoots was not significantly different; means were 53.10 for grand fir and 42.08 for Douglas-fir (table 8). On both tree species, 15-inch twigs were heavily budded, averaging 62.6 new shoots per twig on grand fir and 42.3 on Douglas-fir. Thus, in this high population plot, as also found in the low to medium population plots at Baker and Halfway, densities of larvae in relation to number of buds were essentially similar for the two tree species.

CORRELATION BETWEEN LARVAL DENSITY AND DEFOLIATION

In four cases, significant correlations were obtained between an expression of density of small larvae and percent defoliation of current growth. Two cases were at Douglas-fir plots and two at grand fir plots. Two further correlations, based on larval density in buds, were obtained at Douglas-fir plots by rejecting a single observation considered abnormal because of too few buds in the sample.

Table 8.--*Numbers and density of larvae in opening buds on paired Douglas-fir and grand fir trees, Goldendale, Washington, 1962*

Tree number	Douglas-fir		Grand fir	
	On 4 twigs	Per 100 shoots	On 4 twigs	Per 100 shoots
	- - - - - - - - - - - - - Number of larvae - - - - - - - - - - - - -			
1	42	46.2	136	81.4
2	89	42.6	86	46.5
3	59	24.7	203	60.2
4	120	65.2	110	46.6
5	39	31.7	101	30.8
Total	349	210.4	636	265.5
Average	69.8	42.08	127.2	53.10

Larvae per twig lot.--Larval density and percent defoliation were significantly correlated on Douglas-fir at Halfway in 1959 (r = 0.69), at Goldendale in 1961 (r = 0.635), and also on grand fir at Goldendale in 1960 (r = 0.71). Relationships were linear in each case. Larval counts were transposed from a 4- and 6-twig basis to a 100-twig basis and damage curves compared (fig. 1). Regression lines for the two Douglas-fir plots have an identical slope, but the regression line for Goldendale is at a higher level than that for Halfway. In contrast, the line for the grand fir plot at Goldendale (1960) has a steeper slope and, as populations increase, more defoliation is shown for a given larval density than on Douglas-fir.

When twig lot is used as the independent variable, number of new shoots per twig can affect the damage relationship. However, average number of shoots per twig was 36 at this grand fir plot and 24.5 and 20 at the Douglas-fir plots at Goldendale and Halfway, respectively. Grand fir suffered more damage, even though there were more, rather than less, shoots per twig.

Larvae per unit number of buds.--In the initial analyses, larval density per 100 buds and percent defoliation were significantly correlated (r = 0.775) only on grand fir at Goldendale in 1960. Two further correlations (r = 0.70, r = 0.78) were obtained at Douglas-fir plots by rejecting single trees. Tree 2 at Halfway was rejected because of the scarcity of branches in the lower crown third and tree 1 at Goldendale in 1961 because so few buds were on the twig samples.

Comparison of regression lines shows grand fir again to have a steeper slope and higher defoliation with increasing populations than Douglas-fir (fig. 2), the same as when larvae per twig lot was the independent variable. Regression

lines for Douglas-fir, based on larvae per 100 buds, are not directly comparable with predictive equations already presented (Carolin and Coulter 1972) because of the lack of trees having defoliation exceeding 50 percent. For this same reason, the regression line for grand fir will require validation before it can be used for prediction.

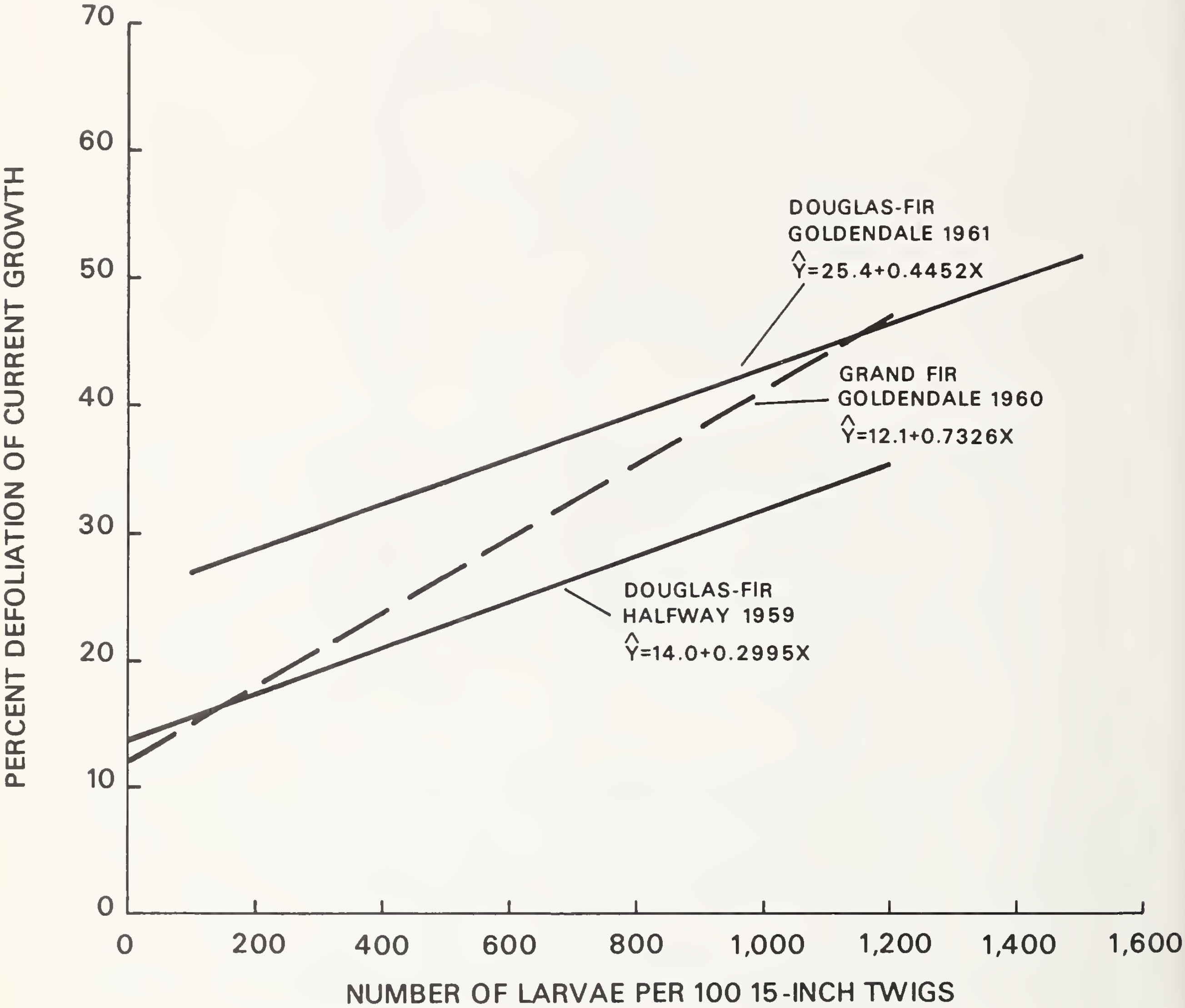

Figure 1.--Linear regression of defoliation of current growth on larval density on twig samples.

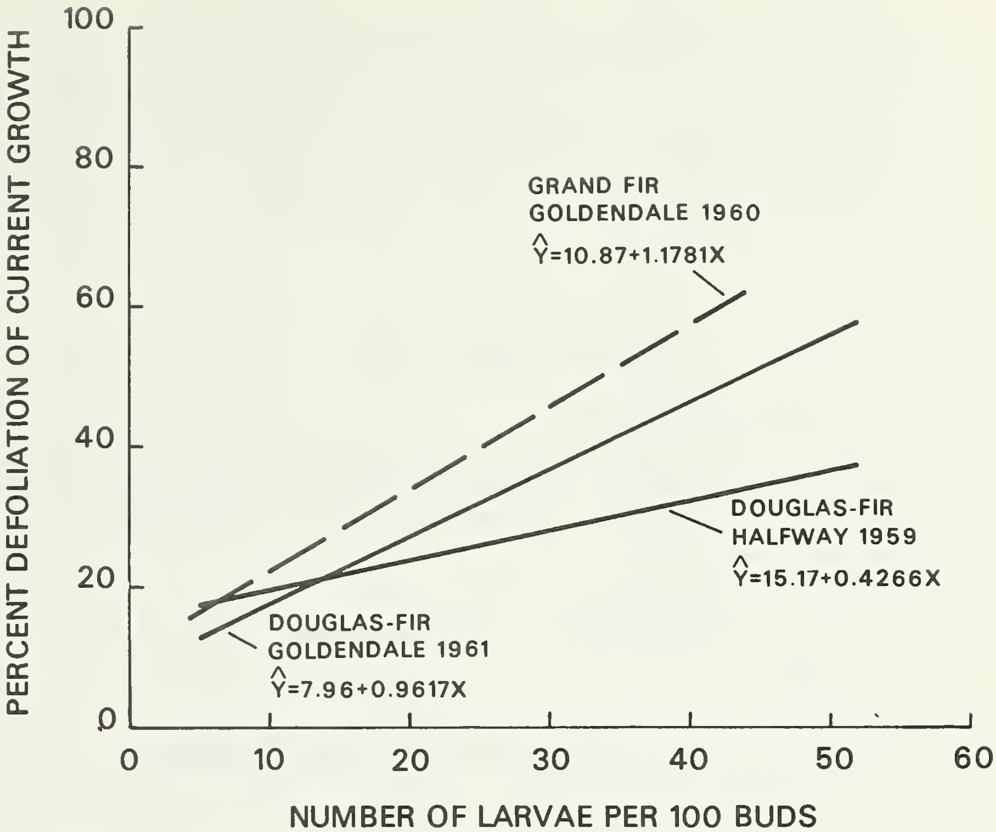

Figure 2.--Linear regression of defoliation of current growth on larval density in buds.

CONCLUSIONS

In answer to the three questions posed at the beginning of this report, the following conclusions are reached:

1. Adjacent grand fir and Douglas-fir trees show strong differences in budworm-caused damage early in an outbreak. Grand fir suffers serious bud damage and incipient top-killing within 4 years, 2 of which involve medium or high populations. Douglas-fir, in the same period, shows only minor damage.
2. A higher incidence of damage on grand fir, as compared with Douglas-fir, cannot be attributed to higher egg or larval populations on grand fir. Egg populations on grand fir and Douglas-fir are similar in the upper crown third, the critical part of the tree so far as damage is concerned; they are dissimilar in the lower two-thirds of the crown, with Douglas-fir having significantly higher populations than grand fir in the lower third. Density of larvae per unit of new shoots is similar between the two tree species; number of larvae per twig lot usually differs.

3. With more intensive sampling, larval sampling can probably be used as a basis for predicting early damage on grand fir; a 10-tree sample at a cluster plot is minimal for predicting defoliation on grand fir, as well as Douglas-fir. After grand fir has suffered serious bud damage, subsequent predictions of defoliation alone are meaningless and special attention should be paid to the incidence of bud-killing and top-killing.

LITERATURE CITED

Carolin, V. M., and W. K. Coulter.
1972. Sampling populations of western spruce budworm and predicting defoliation on Douglas-fir in eastern Oregon. USDA For. Serv. Res. Pap. PNW-149, 38 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Carolin, V. M., and F. W. Honing.
1972. Western spruce budworm. U.S. Dep. Agric. For. Pest Leafl. 53, 8 p., rev.

Edgerton, Paul J.
1973. Big game use and habitat changes in a recently logged mixed conifer forest in northeastern Oregon. *In* West. Proc. 52d Annu. Conf. West. Assoc. State Game & Fish Comm., p. 239-246.

McKnight, M. E., John F. Chansler, Donn B. Cahill, and Harold W. Flake, Jr.
1970. Sequential plan for western budworm egg mass surveys in the central and southern Rocky Mountains. USDA For. Serv. Res. Note RM-174, 8 p. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.

Williams, Carroll B., Jr.
1966. Differential effects of the 1944-56 spruce budworm outbreak in eastern Oregon. USDA For. Serv. Res. Pap. PNW-33, 16 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Williams, Carroll B., Jr.
1967. Spruce budworm damage symptoms related to radial growth of grand fir, Douglas-fir, and Engelmann spruce. For. Sci. 13: 274-285.

Carolin, V. M., and W. K. Coulter
1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

Carolin, V. M., and W. K. Coulter
1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

Carolin, V. M., and W. K. Coulter
1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

Carolin, V. M., and W. K. Coulter
1975. Comparison of western spruce budworm populations and damage on grand fir and Douglas-fir trees. USDA Forest Serv. Res. Pap. PNW-195, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Western spruce budworm populations and damage on grand fir and Douglas-fir were compared. Grand fir showed more damage than Douglas-fir in a given period of time. Egg populations on the two tree species were similar in the upper crown third, but higher on Douglas-fir in the middle and lower crown thirds. Larval density was similar. As larval populations increased, grand fir showed more defoliation than Douglas-fir.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, Douglas-fir, grand fir, defoliation damage.

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Developing and evaluating alternative methods and levels of resource management.
3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

Fairbanks, Alaska	Portland, Oregon
Juneau, Alaska	Olympia, Washington
Bend, Oregon	Seattle, Washington
Corvallis, Oregon	Wenatchee, Washington
La Grande, Oregon	

Mailing address: Pacific Northwest Forest and Range Experiment Station
P.O. Box 3141
Portland, Oregon 97208

GPO 994-576